POSITRONIUM VERSUS THE MIRROR UNIVERSE

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A mirror universe of fermions and forces isomorphic to but distinct from those we see couples directly to our universe only by gravity. Particles at any mass scale enjoying both normal and shadow forces forge an electromagnetic link (by radiative corrections) between the two universes such that mirror particles display conventional electric charges 10^{-3}–10^{-5} e. This produces mixing between triplet positronium and its analogous mirror state through a one-photon annihilation diagram. Consequent effects are contrary to experiment. The possible existence of such a mirror universe is thereby excluded.

The idea of a "mirror universe" is an old one [1]. It involves the existence of a system of particles and forces as yet unseen which is identical to the known system of quarks, leptons, gluons, and electroweak bosons. The only direct (tree approximation) connection between ordinary and mirror matter is via gravity. To each particle or composite of particles of the ordinary universe there exists, in principle, a degenerate mirror particle or composite of mirror particles. We assume that the ordinary and mirror universes are grand-unified in terms of a group $[SU(5)]^2$, $[O(10)]^2$, or a larger group.

A mirror universe is a special case of a shadow universe in which there is no assumed isomorphism between ordinary and shadow structures. Holdom [2] adds a twist to this concept by introducing a third (mixed) form of matter coupled both to ordinary and shadow forces. A loop of such particles generates an effective mixing between the photon and a putative shadow photon

$$\epsilon F_{\mu\nu} F'_{\mu\nu} \,, \qquad (1)$$

which leads to a direct electromagnetic coupling between "our" photon and shadow matter. Shadow particles will display to us small electric charges incommensurate with the electric charge of the electrons. Composites of shadow matter with no net shadow charge will exert small van der Waals forces upon ordinary matter, possibly making terrestrial encounters with cosmic chunks of shadow matter observable [3].

We are here concerned with a mirror universe in which we obtain

$$\epsilon = (\alpha/2\pi)\mathrm{TR}[QQ' \ln(M/\Lambda)] \,, \qquad (2)$$

where Q and Q' generate charge and shadow charge and M is the mass matrix of the mixed matter multiplet. $\mathrm{TR}\, QQ' = 0$ in a grand unified theory, so that ϵ is necessarily small, finite, and cutoff (Λ) independent. Typically, we may write $\epsilon \sim 10^{-3} \ln(m_i/m_j)$. Were all masses and mass differences of the mixed multiplet comparable, we have $\epsilon \sim 10^{-3}$ quite independently of what is the mass scale of the mixed multiplet. Even if the mixed matter lies at the unification scale M, it produces significant photon–mirror-photon mixing. This would be the case, for example, if the unification group were $[SU(5)]^2$ and the mixed multiplet transformed according to the real representation $(5, \bar{5}) + (\bar{5}, 5)$. The logarithmic factor, $\ln(m_{tt} m_{dd}/m_{dt}^2)$, would be expected to be ~ 1, where subscripts d and t signify doublets or triplets under the unbroken $[SU(3) \times SU(2)]^2$ subgroup.

In the case of SU(5), electromagnetism (more

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properly, part of electromagnetism) emerges as an abelian U(1) gauge theory at the same energy scale at which SU(5) breaks. This is not necessarily the case. For example, the unifying group $[O(10)]^2$ could break at M to $[SU(4) \times SU(2) \times SU(2)]^2$ leaving the photon essentially nonabelian, so that ϵ as given by (2) still vanishes. At a second and lower mass scale M', we imagine the breaking to $[SU(3) \times SU(2) \times U(1)]^2$. Eq. (2) no longer vanishes since once degenerate multiplets of mass $\sim M$ now receive splittings $\sim M'$. It follows that $\epsilon \sim (\alpha/2\pi) \ln(1 + M'/M) \sim (\alpha/2\pi) \times (M'/M)$. In these hierarchical symmetry-breaking scenarios, there is a possibility of obtaining a suppression of ϵ. However, the degree of suppression is limited. In the case above – the only plausible example I can construct – Georgi and Nanopoulos have shown [4] that $M'/M > 10^{-3}$, for otherwise the successful GUT prediction of $\sin^2\theta_W$ is lost. We conclude that in any mirror universe with mixed matter multiplets that

$$\epsilon > 10^{-6} . \tag{3}$$

In the remainder of this paper, we argue that the above bound on ϵ is probably inconsistent with presently available data [5] concerning the observed behavior of positronium:

(1) Positronium is produced by positron collisions as a statistical mixture of spin-1 and spin-0 states in the expected 3 : 1 ratio.

(2) The ortho–para splitting receives a contribution of about $f = 8.7 \times 10^4$ MHz from the one-photon annihilation diagram involving orthopositronium.

(3) The measured lifetime of orthopositronium for its decay into three photons (about 140 ns) agrees with its theoretically computed value to a precision of 10^{-3}. These experiments are performed with a typical positronium age of one or two mean lifetimes.

Consider the effect upon the positronium system of the existence of a degenerate mirror system. Orthopositronium is connected via a one-photon annihilation diagram to its mirror version, giving rise to ordinary–mirror oscillations of characteristic frequency ϵf. More precisely said, the mass eigenstates (Ps + Ps′) and (Ps – Ps′) are split in energy by $2\epsilon hf$. A state which is initially orthopositronium evolves according to

$$P(t) = e^{-\Gamma t} \cos^2(\omega t) ,$$

where $\omega = 2\pi\epsilon f$, Γ is the decay rate of orthopositronium, and $P(t)$ is its survival probability. It cannot be that $\omega \gg \Gamma$, for though this would produce an effectively exponential decay, it would imply a production ratio of triplet to singlet positronium of 1.5 : 1 rather than 3 : 1. (Half the orthopositronium would decay invisibly as mirror matter.) Agreement between calculated and measured lifetimes implies $\omega^2/\Gamma^2 < 10^{-3}$, or

$$\epsilon < 4 \times 10^{-7} . \tag{4}$$

Since (3) and (4) are in evident conflict, the notion of a mirror universe with induced elctromagnetic couplings of plausible (or otherwise detectable) magnitude is eliminated. The unity of physics is again demonstrated when the old positronium workhorse can be recalled to exclude an otherwise tenable hypothesis.

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